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B70 06058

SUBJECT: Surface Relief on Mars
Case 105-7

DATE: June 22, 1970

FROM: E. N. Shipley

## ABSTRACT

Theories and data correlating visual markings on Mars with surface relief on the planet are reviewed. A long standing prevailing opinion held that the dark areas were lowlands. In recent years, there has been increasing theoretical evidence indicating that, contrary to this opinion, the dark areas were elevated above the rest of the surface.

Direct evidence of surface relief on Mars has been obtained through radar ranging measurements and through $CO_2$ spectroscopic experiments. These data indicate that there is surface relief of 10 km but that there is no correlation between surface relief and visual markings. However, it is possible to interpret the radar data as indicating that dark areas are at least locally lower than surrounding regions.



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MEMORANDUM FOR FILE

## I. INTRODUCTION

It has long been accepted that the dark regions of Mars represent low regions of the planet's topography. Recently there have been developed new ideas that challenge this on theoretical grounds, while at the same time measurements of the surface relief have been obtained through radar and through spectroscopic techniques. As we shall see, the results remain ambiguous.

This memorandum is a survey of current ideas and measurements on the elevation profile of Mars. This question is of major significance since hypotheses about dynamic processes, especially in the dark areas, are in general related to the elevation of the region, and the different behavior of the light and dark areas has been attributed to a difference in elevation.

## II. HISTORICAL DEVELOPMENT

Three types of Martian surface may be identified from Earth.* The most distinctive regions are the polar caps, which are white deposits of solid $CO_2$ or water ice. The remainder of the surface is divided between bright areas, or deserts, and the distinctively darker regions called maria. It was originally thought that the maria represented bodies of water; this accounts for their name.

Many dynamic processes may be seen on Mars. The polar caps undergo a seasonal advance and regression. In each hemisphere, coincident with the retreat of the polar cap, a wave of darkening that affects only the maria sweeps

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*For a more complete description of Mars, see de Vaucouleurs, 1954, or Antoniadi, 1930.

from the pole toward and beyond the equator. In addition, the boundaries between bright and dark areas undergo secular changes. There are other observed phenomena that show that the surface of Mars is not static.

No surface relief can be seen on Mars from earth-based telescopes. The most sensitive method of detecting mountains is by looking at irregularities in brightness near the terminator. Tops of mountains should still be illuminated after their bases have moved into the darkness beyond the terminator. Bright regions have in fact been seen beyond the terminator, but because they do not appear regularly in the same spot, it has been concluded that they represent clouds rather than surface elevations (Lowell, 1906).

Lowell originally estimated that mountains of 2500 feet (0.8 km) elevation should be capable of being detected. Hence, the absence of detectable surface relief would indicate that Mars possessed an exceptionally flat surface. A more recent estimate of the minimum detectable height (Tombaugh, 1961) indicates that the smallest perceptible height is 4.7 km (15,000 feet. Moreover, this estimate presupposes that the feature has steep slopes. It has been pointed out (Russell et al., 1945) that features of much greater height would be undetected if the slopes were shallow (say 1°).

Based on observations from the earth, the only conclusion that may be reached about Martian surface relief is that any features with a vertical profile in excess of about 5 km must possess shallow slopes. Of course, all elevations are relative to the mean Martian spheroid. It is well known that the planetary radius of Mars is greater at the equator than at the poles--the excess amounts to 36 km on the basis of visual measurements, but only 18 km based on the perturbations to the orbital paths of the two Martian satellites, Phobos and Deimos (de Vaucouleurs, 1964). It is possible that the discrepancy between the optical and dynamical measurements arises from darkening of the polar limb (Leighton et al., 1969), an effect seen by Mariners 6 and 7.

Despite the lack of observable surface relief, it was generally thought, prior to 1964, that the bright areas of Mars represented elevations, and the dark areas, lowlands (Sagan and Pollack, 1968). This belief does not appear to have been based on any direct evidence, but seems rather to be a natural consequence of the general conception of the planet.

One of the dominant factors of the early ideas of the planet was the seasonal changes in the dark areas of the planet. It has long been hypothesized that the wave of darkening, which sweeps across the dark areas from the polar areas toward and past the equator each spring, is caused by growth of some vegetative life form in response to increasing moisture from the melting polar cap. In addition, the growth of the vegetative material can explain the regeneration of dark areas and the secular changes on the planet. Kuiper (1952) has argued that the colors seen in the dark areas, and the dynamic behavior of the areas, can be explained by an organism similar to lichens. Moreover, the conditions on Mars seemed to be compatible with their existence, since on earth lichens can endure great extremes of temperature and humidity.

The vegetative hypothesis received support from infrared measurements (Sinton and Strong, 1960) that indicated the dark areas were a few degrees warmer than the bright areas. Sinus Meridianii, for example, was 8°C warmer than the surrounding bright areas. Thus elevation differences can quite simply explain the distinction between the bright and dark areas on Mars; the organisms which produce the dark coloration of the lowlands are not viable in the colder regimes of the highlands.

In addition, the presence of clouds and frost patches in the bright areas can be interpreted as indicating that the bright areas are elevated (Tombaugh, 1968). On the basis of terrestrial analogy, one would expect the higher elevations to be colder, and hence to permit the formation of frost patches. The clouds over the bright areas are attributed to adiabatic cooling of the atmosphere as it rises to pass over the elevated regions.

Thus the concept of low dark and high bright areas formed a consistent picture, although there was a definite sparcity of facts. It should also be noted that at least some observers were very cautious of accepting the biological explanation of the dynamic effects on Mars.

In a series of observations during the 1954 and 1956 oppositions, Kuiper (1957) detected little coloration in the maria during local springtime. He suggested that the absence of the expected more vivid colors meant that a non-biological explanation of the maria was possible, and that the dark regions might represent lava fields. Dynamic effects might then represent the result of winds, with seasonal wind patterns giving rise to the consistent seasonal effects.

It was subsequently suggested (Rea, 1964) that the difference between the light and the dark areas might be in the size of the particles--the bright areas being covered with finer particles than the dark areas. The separation between the light and dark areas would arise from elevation differences; the lowlands would be covered with fine dust and so be bright, whereas winds would remove the fine material from higher areas and from slopes, leaving them dark.

Several additional ideas have been developed to support the hypothesis that the bright areas were lowlands. Wells (1965) suggested that the stationary white clouds which formed over the bright areas at the border with dark areas might be analogous to the lee wave clouds on the earth. The lee wave clouds form due to the disturbance caused by the mountain, which causes air to be transported to heights at which water vapor condenses. The clouds have the property of remaining fixed in location, rather than moving with the airstream. If the analogy between the stationary Martian clouds and the lee wave clouds is valid, it would indicate that the dark areas represent mountain ranges.

Occultation measurements from the Mariner IV mission revealed that Mars had an atmospheric pressure at the surface of only 4 to 6 millibars, and, since the presence of similar quantities of $CO_2$ had been detected by earth-based spectroscopy, the atmosphere must be largely $CO_2$ (Kliore et al., 1965). Based on this information, O'Leary and Rea (1967) showed that the frost patches would occur preferentially in lowlands because of the increased $CO_2$ pressure there. Their study was based on a calculation of the radiation budget at the surface, and several fairly restrictive assumptions were necessary.

A subsequent study of the expected temperature variation with elevation (Sagan and Pollack, 1968) revealed that the behavior on Mars should not be analogous to the earth. Primarily because of the low atmospheric pressure on Mars, the effects that cause earth highlands to be colder than lower regions are ineffectual on Mars, and the dominant factor that effects the temperature is the surface albedo. Thus the observation that the dark areas are warmer than the bright is not in itself indicative that the dark areas are lower.

## III. RECENT DATA

Direct measurements of the surface relief of Mars have been made by two methods: radar ranging (Pettengill et al., 1969) and measurement of the amount of $CO_2$ overlying different regions of the planet (Belton and Hunten, 1969; Wells, 1969). Both of these techniques showed surface relief of major dimensions, that is, more than 10 km between the lowest and highest points.

The radar experiment measures the range to the sub-earth point. As the planet rotates, measurements are made on a locus of points at essentially constant latitude. The latitude of the sub-earth point changes gradually due to the changing orbital position of the earth and Mars. The radar data (Pettengill et al., 1969) were obtained during the 1967 opposition when the latitude of the sub-earth point was about +21.5°. Further data at different latitudes was obtained during the 1969 opposition. Preliminary results are already available, but they have not yet been analyzed in terms of the topography (Evans, 1970).

In the radar ranging experiment, the surface relief is given by the variation in the residual range as the sub-earth point moves over the surface of the planet. The residual range is the distance remaining after corrections have been made for the normal changes in the distance between the radar station and the center of mass of Mars, arising from the orbital motion of Mars and the earth and from the rotation of the earth.

Each individual range measurement was accomplished by an approximately 10-minute period of transmission followed by an equally long reception period. This procedure was necessitated by the low signal-to-noise ratio of the returned signal. As a result, the range was averaged over a 10-minute period, during which the sub-earth point on Mars would move by about 2.5° in longitude. In the eight week interval over which measurements were made, the sub-earth latitude shifted by about 5°. The quoted results do not distinguish among the latitudes. The averaging in longitude and latitude limits the surface resolution of the radar experiment. The resolution is comparable to that achieved with earth-based visual telescopes. The range uncertainty for a single radar measurement was typically 2 km.

The measurement of the quantity of $CO_2$ overlying different portions of Mars was accomplished by measuring the intensity of a $CO_2$ absorption line. It is estimated that elevation differences of 1 km can be detected at the surface of the planet (Belton and Hunten, 1969). The resolution on the surface of the planet is a square about 15 arc degrees (about 900 km) on a side. It appears that reasonable data may be obtained for latitude up to 45° from the sub-earth point, and so, for each opposition, it is possible to obtain a topographic map of the entire mid-latitude region. However, data were obtained over only half of the longitude range during the 1969 opposition. These data are in reasonable agreement with the radar data at latitude +21.5°.

The conclusion reached by the authors of both the radar ranging experiment and the $CO_2$ spectroscopic experiments is that there is no obvious correspondence between the topography of the planet and the permanent visual surface features. In Figure 1, the radar data is shown together with a map of Mars. Although some of the bright areas are elevated, there is not a uniform relationship between brightness and elevation. In order to put the result on a quantitative basis, Pettengill et al. (1969) calculated the cross-correlation function between the elevation profile they obtained and the brightness values given by de Vaucouleurs (1967). The results indicated that no meaningful correlation existed.

On the other hand, Binder (1969) has further analyzed the radar profile data. He assumes that linear Martian markings are the result of a planet-wide fracture system and hence are indicators of the planet's topography. On this basis he can construct a topographic map that correlates well with the radar elevation profile. The principal conclusions that Binder reaches are that dark areas occur in local depressions or on slopes; that the dark linear features (the canals) occur in local troughs; and that the bright areas, specifically Elysium and the Amazonis Desert region are elevated above the surrounding regions. Some of the more prominent correlations between elevation and surface markings are noted on Figure 1.

The essential feature of Binder's analysis is that dark areas occur in local depressions, although the dark features are not always low on an absolute basis. Such a relationship would not be apparent in the cross-correlation function of Pettengill et al., since that depends only on the value of the elevation at a specific point, and not on the relationship to surrounding areas.

It must be noted, however, that the uncertainty on the individual data points is quite large, and that many of the small scale features in Binder's elevation curve (see Figure 1) are not uniquely demanded by the data.

It appears that the topographic map developed by Binder does not agree with that given by Wells (1969). However, the two maps are difficult to compare because Wells' map, based on the $CO_2$ spectroscopic data, covers a broad range of the surface with relatively poor resolution, whereas Binder's map covers only a limited area but with substantially greater resolution.

## IV. CONCLUSIONS

Until the advent of the radar ranging data (Pettengill et al., 1969) recent theoretical interpretations of the available observational data supported the conclusion that the dark areas represent highlands. Direct measurements of the profile by both radar and by $CO_2$ spectroscopic measurements have led to the conclusion that there is no correlation between surface brightness and surface topography. However, Binder (1969) has found evidence in the radar data that dark areas either occur in regions that are depressed, at least locally, or else on slopes.

The data are inadequate at this time to allow a definite judgment of the merits of the elevation correlation, or its lack. It may be expected that further radar data will clarify the situation.

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E. N. Shipley

Attachments
References
Figure 1

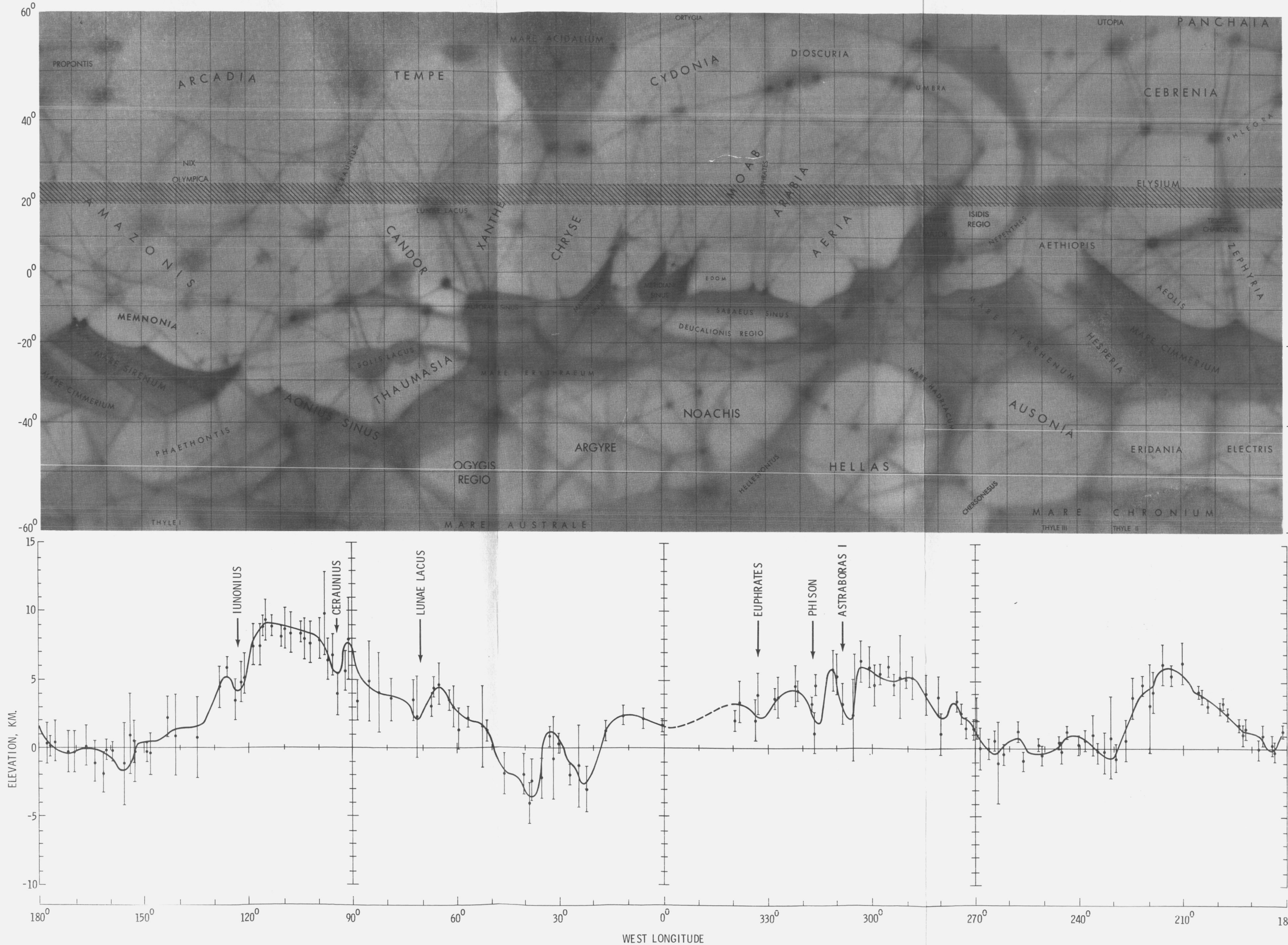


FIGURE I - ELEVATION PROFILE OF MARS. THE DATA REFER TO THE CROSS-HATCHED AREA NEAR +21.5° LATITUDE. THE ZERO LEVEL FOR THE ELEVATION DATA IS ARBITRARY. THE DATA WERE OBTAINED BY PETTENGILL et al (1969). THE CURVE AND THE FEATURES IDENTIFIED ON THE ELEVATION GRAPH ARE FROM BINDER (1969). THE MAP IS A MERCATOR PROJECTION PUBLISHED BY THE U. S. AIR FORCE, ACIC, MEC-1 PROTOTYPE, APRIL, 1968.

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